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FOREST INSECT INVESTIGATIONS

A PROGRESS REPORT ON THE HEMLOCK-BORER INVESTIGATION IN 1938

by

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INTRODUCTION

At the request of the Indian Service, U. S. Department of the Interior, an investigation of the hemlock borer infestation on the Menominee Indian Reservation was begun in 1937 by L. E. Yeager of the Bureau of Entomology and Plant Quarantine. A survey was made at this time, and 49 experimental plots were established. A report was submitted to the Washington office in December 1937. As a result of this survey, it was decided to continue the investigation for several seasons. Following Yeager's resignation in June 1938, the project was continued by the writer.

This season's studies were directed toward the accumulation of biological and physiological data. Additional survey notes were also collected and added to those of the previous season.

BIOLOGICAL STUDIES

Length of Life Cycle

In order to get information on the duration of the life cycle, 9 borer-free trees were cut and a section from each of their trunks was caged on June 7 and 8. On June 23, by which time beetles were common, 20 females and 10 males were introduced into each cage. Attack on these caged sections by this method was successful and furnished important information on the life cycle.

The caged portions of two of these trees were carefully peeled in October and showed that larvae from eggs laid in late June or early July were mature or nearly mature, and that many of them had completed their cambium feeding and were tunneling into the bark, preparatory to cutting hibernation cells. It is expected that larvae in the other caged sections will emerge as adults next June. These observations indicate that normally the life cycle is completed in 1 year. However, borer development in infested trees was observed weekly throughout June and July and bimonthly beginning in August, and there is evidence that under certain conditions the life cycle may last 2 years.

As the result of a late summer blowdown, a number of trees which had not been previously infested were attacked in August in the Camp 29 area. Some of these trees were completely blown down; others were only partially broken or blown over. Considerable variation in size in larval populations of the trees was found in December. These size variations suggest that possibly larvae

from eggs laid late in the summer (August) may have either a 1- or 2-year cycle. In the first case, larvae developing on suitable host material would become adults and emerge the following August. In the second case, larvae developing on host material offering a greater natural resistance would grow so slowly that they would not mature until the next fall and would become adults the second June. This will be investigated in more detail in 1939.

Pupal Period

Pupation in standing trees began about June 1 and continued until at least mid-July. On May 19 Yeager found what appeared to be a pupa in the early stage of development in the upper surface of a salvaged log cut from the upper part of a dead tree in the Camp 23 area. The specimen was crushed in barking and, unfortunately, was not preserved. In the light of findings regarding high subcortical temperatures and early pupation, discussed later in this report, it seems possible that this may have been a hemlock borer which had pupated early. Yeager made a careful search, by barking logs cut from all heights, but did not find any more pupae on that date. He was also unsuccessful May 20 in his efforts to find pupae or even prepupae among more than a hundred specimens in the Camp 29 area. No further observations on beetle development were recorded until the arrival of the writer on June 3.

On June 3 and 4 collections of pupae were made by Richard Delaney, Forest Supervisor of the Menominee Reservation, and the writer in the areas of Camps 23 and 29. Two partially colored (black) pupae were found in the borer population of the upper

surface of winter-cut logs on the top of an unsheltered log deck. All those collected from standing trees were white, and a quantitative examination showed that only 20 percent of the borer population in the bark cells had transformed from larvae to pupae at that time. Delaney, who had been making random observations of borer development for his personal information, stated that these were the first pupae found that season. Table 1 contains quantitative data on subsequent random collections made until beetle emergence began on June 15.

The fact that pupae in logs appeared to develop earlier than did pupae in standing trees led to further investigation during the following week. Pupae were found in the upper surface of top logs in decks at least 6 to 10 days earlier than on the under surface of the same logs, which indicated a relationship between high subcortical temperatures and earlier pupation. It seems quite probable that high subcortical temperatures explain the more advanced stage of development of pupae found in the top logs of decks, as compared with that of pupae found in standing trees.

An attempt to determine the length of the pupal period was not successful. Fifty specimens collected in June were examined at 3-day intervals, and individual records were kept of their development. It was impossible to rear them to adults in their bark cells because the peeling in to the pupal cell, necessary to make examinations, permitted desiccation and eventually caused the death of the pupae. The collection contained specimens in all stages of pupal development, however, and for about 1 week, during which period further changes occurred, it was possible to make some observations on the approximate length of time required to complete development. During June this period would appear to be from 2 to 3 weeks.

Table 1

Field notes on 1938 borer development, with reference to the percentage of borer population in the bark which had pupated prior to date of examination.

Date of Examination	No. of Specimens Examined	Location	Pupae %	Prepupae %
June 4	40	Camp 29	20	--
June 6	50	Camp 29	30	--
June 10	136	Camp 29	60	30
June 14	78	Camp 29	66	--

Beetle Flight Studies

Beetle emergence from standing trees was observed for the first time on June 15. It is probable that a limited amount of emergence from log decks may have occurred as much as 5 days earlier in the Camp 23 area. The peak of emergence was reached about the end of the month. This was determined by periodically examining selected trees and marking the emergence holes. Weekly collections from caged infested materials also gave further data on this subject. The beetle emergence from a 21-inch (DBH) hemlock is given in table 2. (Information on parasite emergence from this material will be found in table 3, page 14.) This tree was felled and barked to a height of 30 feet on June 18. The bark from the various sections of the tree was caged, as indicated, in six cages.

Although beetles were found on June 15, oviposition was observed for the first time during the last week in June. It continued intermittently throughout August. The greatest oviposition activity was observed during the first half of July. A marked reduction in beetle emergence occurred about the second week in July and caused such a noticeable decrease in oviposition activity toward the end of the month that it was at first assumed the beetle flight for the season was drawing to a close. Following a warm dry period in late July and early August, however, beetle emergence apparently was resumed, and ovipositions were observed as late as August 27.

Since other work required the writer to be in Ohio during September, no detailed observations were made during this month. It was apparent, however, that oviposition activity was practically at a close the last of August. The forest supervisor and his cruising crew reported that no beetles were noticed in the forest during September.

Table 2

Beetle Emergence from Caged Bark Sections

Cage No.	Tree Section: Diameter Inches	Tree Section: Height Feet	Orientation of Bark Section	June 18-20	June 21-24	June 25-27	June 28-29	June 30 July 7	July 8-11	July 12-22	July 23 Aug. 1	Aug. 2-23	Aug. 24 Oct. 1
1	20.7-16.2	0-10	North	3	16	26	13	17	1	6	None	None	None
2			South	23	25	18	9	4	None	None	"	"	"
3	16.2-15.3	10-20	North	21	28	39	18	15	"	4	"	"	"
4			South	23	23	31	7	10	1	8	"	"	"
5	15.3-14.7	20-30	North	6	30	36	23	30	2	9	"	"	"
6			South	18	11	24	4	3	None	1	"	"	"
Total				94	131	175	74	79	4	28	"	"	"
No. of days in period				3	4	5	2	8	4	11	10	22	39
Average daily emergence				31	33	68	37	10	1	2	0	0	0

Length of Life of the Beetles

Six lots of beetles were placed in rearing cages during the early part of the beetle flight period, and the mortality was recorded daily. Three of the collections consisted of specimens taken as they crawled about on the trees and three were collections from caged infested bark. The beetles were supplied with moisture (by means of a gauze wick which extended through the cage) and with bark bearing the type of moss on which feeding had been observed. Many of the field-collected beetles apparently were injured when being trapped or transferred, and they died within 48 hours. The beetles are very active, and it is difficult to collect and handle them in numbers without some loss. The most favorable time for transferring them from the collecting cages to the rearing cages was found to be in the cool period of the morning, before they began to move about. The maximum time the beetles remained alive in the cages was 10 days. It is probable that "free" beetles live longer than this, as is evident by the fact, previously mentioned, that although beetles were found on June 15, oviposition was first observed during the last week of the month.

Adult Feeding Habits

Observations were made both in the field and under caged conditions to determine the food of the adult beetles. In the field numerous instances of beetles feeding on a moss, Dicranum montanum Hedw., which grows in abundance on the bark of hemlock trunks, were observed. Two green trees were felled in the beetle-infested region of Camp 24, and 2 days were devoted to observing whether any of the

beetles fed on the foliage. Although the beetles were quite abundant, and many were crawling about on the felled trees, none was observed to feed on either the old or new needles of the foliage. Under caged conditions, the beetles fed to a limited extent on the new needles of the foliage, but appeared to prefer the above mentioned moss.

Oviposition Habits

The female beetle crawls about on the tree trunk inserting her ovipositor in various crevices in the bark, apparently seeking one of satisfactory depth and width. When one has been located there is usually a pause of about 20 seconds while she lays the egg. With a little practice it is possible by simply observing the beetles to determine with accuracy when an oviposition is made. The favorite place for ovipositing is beneath loose flakes of bark, and the eggs are usually laid singly, although it is not unusual to find two or even three together. Instances of as many as eight eggs in a single mass were found, but it is not known whether these were laid by one beetle or by several which chanced to choose the same crevice. The duration of the egg-laying period for an individual was not determined.

Indications of a phototrophic response on the part of the ovipositing beetles suggested study of light and temperature influence on oviposition, but this was carried on only to a limited extent. These observations indicated a relation between air temperature and the daily migration of the female beetles to the trees. The time at which the beetles were first observed on the trees was noted daily,

together with the air temperature reading in the shade. This was usually between 70° and 75° F.

Three days were spent on oviposition observations. Air temperature, light intensity in footcandles, relative humidity, and sky and wind conditions were recorded hourly. Bark temperature, height (above ground level), location (with reference to quadrant), and exposure (sun or shade) were noted for each oviposition. The diameter breast high of each tree on which oviposition was observed was also recorded. Eighty percent of the ovipositions observed were at bark surface temperatures between 82° and 92° F. The range was 75° to 95° F., with the optimum at about 86° F.

This study was preliminary in nature, and the observations were too limited to warrant more detailed analysis of the data. Further study will be made in 1939.

Biotic Potential

The probable biotic potential was determined by dissecting a small number of female beetles. Some beetles apparently would have produced as many as 160 to 180 eggs. Only about one-third to one-half of this number were mature at the time of examination. The remainder were immature eggs about half the size of the mature.

Sex Ratio

The sex of 484 beetles emerging from caged material was determined. This could easily be done with the aid of a hand lens, as the last ventral segment of the male is more deeply notched than that of the female. Of these 484 beetles, 225 were males and 259 were females, approximately a 1 to 1 sex ratio. In the field collec-

tions females usually predominated, due undoubtedly to the fact that male beetles are more active and thus more difficult to collect.

Incubation Period

During the July oviposition studies 50 eggs were marked in the field, and blocks of bark containing other ovipositions were brought into the laboratory for observation. Apparently the laboratory conditions were not satisfactory as only one instance of hatching was observed out of 14 eggs collected. In the field it was found difficult to relocate and examine the eggs without injuring them, even when the approximate point of oviposition was indicated by a carpet tack. Satisfactory data were obtained on only a small percentage of the eggs. This indicated that normally the eggs hatch in about a week, with temperature exerting an influence on the length of the incubation period. Cool temperatures may prolong this period several days.

Egg Mortality

It was also the intention of the writer to obtain from the above observations data on the borer mortality in the egg stage and early larval stages. Such a small percentage of the larvae was recovered, however, that a satisfactory estimate could not be made. Observations will be continued in 1939.

Winter Larval Mortality

Bimonthly observations on larval mortality were begun in August 1938 and will be continued throughout the winter. The December examination showed very little winter larval mortality. For the

larger larvae of early summer ovipositions the mortality was less than 5 percent and for the small larvae of late summer ovipositions it was between 5 and 10 percent. A low winter mortality would be expected up to December because of the mild weather.

The hemlock borers overwinter both as mature larvae in cells cut in the bark and as immature larvae in their galleries between the cambium and wood. The lower mortality for the larger larvae is probably due in part to the fact that a major portion of this group overwinters in the bark, which is not as moist as the cambium and in which, therefore, temperature fluctuations would have little effect on them.

Parasites

Periodic collections of parasites were made during their activity. Four, and possibly five, species were present. Three of these have been identified as Odontaulacus bilobatus Prov., Atanycolus sp. and Coeloides sp., the first two being the more common. Atanycolus sp. and Coeloides sp. are apparently undescribed. One specimen of a pupa of an egg parasite, probably a Telenomiid, was collected.

The effectiveness of parasites as a control measure has not been determined, and quantitative data on this factor, in terms of parasites and borer larvae per unit area of bark, are being collected. These data will be given in the final report made at the close of the present investigation. For those interested only in a rough estimate, it may be stated that instances of 50 and 60 percent parasitization have been found, but it is doubtful if parasites will ever prove a satisfactory control measure for the hemlock borer.

Very limited information was secured concerning the biology of any parasite. O. bilobatus was the most abundant, and it was common to see as many as a dozen males of this species clustered about a recently emerged female. The males seemed to show a tendency to congregate around the trees from which the females were emerging. These were usually trees which had been attacked by the borers the previous year. The species of Atanycolus and Coeloides, and what is probably a dipterous parasite were also found to emerge from trees which had been attacked by the borers the previous season.

Both O. bilobatus and Atanycolus sp. were observed during the latter part of June and throughout July. The writer was absent from the reservation, engaged in other duties, during the first three weeks of August. Observations during the last week of August failed to reveal the presence of O. bilobatus in any part of the area, although Atanycolus sp. was numerous. This suggests that it may emerge over a longer period than O. bilobatus. Table 3 shows data on emergence of these species from caged material.

Both these species were observed ovipositing on trees which had recently been attacked by the borer and upon which the beetles were ovipositing at the time. Although sections of bark upon which parasites had been found were removed and examined under both hand lens and binocular, no eggs could be found to indicate whether the egg is laid in the borer gallery or in the body of the young larva. However, as is common with closely related species, the former is probably the case. These trees contained both recently hatched larvae and unhatched eggs of the hemlock borer. It would appear,

Table 3

Parasite Emergence from Caged Bark Sections

Cage No.	Tree Section Diameter Inches	Height Feet	Orientation of Bark Section	June 18-20	June 21-24	June 25-27	June 28-29	June 30 July 7	July 8-11	July 12-22	July 23 Aug.	Aug. 24 Aug. 2-23	Aug. 24 Oct.
1	20.7-16.2	0-10	North				0	7	11	5	5	None	None
2			South			6		8	12	2	4	"	"
3	16.2-15.3	10-20	North			1	1	7	10	2	5	3	"
4			South	None	None	6	1	13	4	3	1	None	"
5	15.3-14.7	20-30	North			2	0	7	2	1	8	"	"
6			South			7	7	12	3	1		"	"
Total Odontaulacus bilobatus Prov.						23	10	54	39	12	13	2	None
Atanyc sp.									3	2	5		"
Average daily emergence						8	5	7	10	1	2	0	0

however, from the depth beneath the bark to which the female parasite inserted her long ovipositor that it was an early larval stage and not the egg stage which was being parasitized. Fall examinations showed partially developed larvae of what appeared to be O. bilobatus attached to and feeding upon living borer larvae.

Predators

The woodpeckers are the most prominent of the hemlock borer predators, but their effectiveness as a control measure has not been definitely determined. Observations in 1938 indicate that heavy woodpecker attack represents the removal of only 10 larvae per square foot and that, moreover, it results in the destruction of numerous parasites. Quantitative data on these factors are being collected in connection with the parasite studies and will be given at the close of the investigation. The information obtained in 1938 indicates that the predators are less effective than the parasites as a control factor.

PHYSIOLOGICAL STUDIES

Susceptibility of Various Tree Conditions to Attack

Inasmuch as other species of Melanophila have been considered as primary by certain investigators[1], and Yeager had suggested that M. fulvoguttata should be so considered under certain conditions, an experiment designed to obtain data bearing on the question was set up in June 1938. Twenty-seven hemlock trees, representing mature

[1] Salman's Studies of M. californica at the California Station, 1937
De Leon, Donald, Studies of M. drummondi in Douglas Fir in Yosemite National Park, 1937

(200 years) and overmature (250-275 years) age classes, were selected in a stand which was relatively free of hemlock borers. The trees were selected in groups of three. Care was taken to have the trees in each group as nearly identical as possible, especially as to condition, diameter, vigor, and age. The aim was also to have the groups uniform with reference to site conditions and freedom from hemlock borers. Size is unsatisfactory as an indicator of age, even when limited to trees of the same crown class (table 4). Although it was impossible to determine the exact age of the larger trees even with a 10-inch increment core drill, actual age counts were taken for each of the cut trees, and the increment cores used as indicators of age in grouping the other trees.

One tree of each of the nine groups was felled across a rustic scaffold in such a way that the butt was left hanging to facilitate the attachment of a cage to the trunk. At the same time a second tree of each group was partially girdled at a height of 1 foot from the ground, a strip of cambium 4 inches wide and extending halfway around the trunk being removed. The remaining tree of each group was left as a check. A cylindrical cage of 16-mesh wire clothwas placed on each tree in such a way as to enclose a section of trunk approximately 3 1/2 feet long above a point approximately 6 feet from the ground (figure 1). All these trees were treated and caged during the period June 7 to 9 inclusive.

Twenty female and ten male beetles were placed in each cage on June 23, and on October 20 examination of the three trees (Nos. 81, 82, and 83) in one group showed that the caged sections of all three

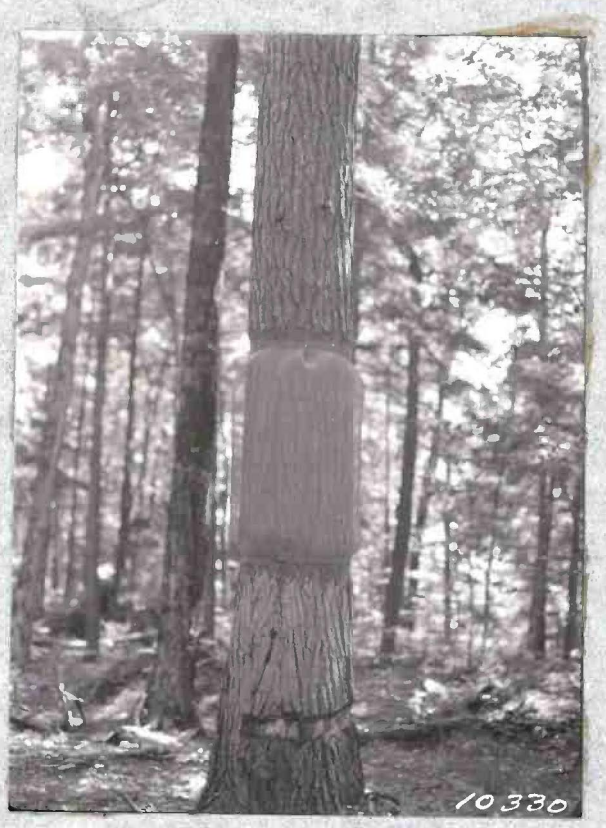


Figure 1

Type of cylindrical cage used to enclose sections of tree trunks in the study of susceptibility of various tree conditions to attack.

Table 4

Size of Caged Trees and Method of Treatment

Diameter Class	Treatment											
	Felled June 7-9, 1938 Infested June 23, 1938				Girdled June 7-9, 1938 Infested June 23, 1938				Check Infested June 23, 1938			
	Tree No.	DBH	Crown Class	Age	Tree No.	DBH	Crown Class	Side Girdled	Tree No.	DBH	Crown Class	
25" - 32"	60	25.6	D	275	61	25.3	D	West	62	26.2	D	
	63	31.0	D	278	65	32.7	D	West	64	31.8	D	
	66	26.3	D	231	67	26.8	D	West	68	26.2	D	
	76	25.7	D	235	77	25.8	D	East	75	25.9	D	
19" - 20"	70	19.6	D	227	71	20.1	D	West	69	19.8	D	
	72	20.0	D	246	74	19.4	D	East	73	19.6	D	
	78	19.2	D	247	79	20.4	D	West	80	20.5	D	
	81	19.1	D	170	83	19.3	D	East	82	18.9	D	
	84	13.0	I	175	86	13.7	I	East	85	13.9	I	

had been infested. It is therefore presumed that this technique was effective with the other trees also.

The susceptibility of the trees to borer attack varied, however, with the various treatments. Borer attack had been successful only on the cut tree, No. 81. Fourteen attacks were found on the upper surface of the caged section of this tree. All of the 14 larvae were alive and apparently in a healthy condition. Three of the larvae had tunneled into the bark and were cutting their hibernation cells. Others had completed their cambium feeding and were commencing to tunnel into the inner bark tissue (figure 2). Numerous incipient galleries indicated attacks on tree No. 83, but no living larvae were found. The maximum length of these incipient galleries was about 3 inches, with the majority of them attaining a length of only 1 to 2 inches. In number these incipient attacks averaged 1.6 attacks per square foot of bark surface. The term "incipient galleries" is used here to designate the galleries made in the cambium tissue by the early feeding of young larvae which are killed by the natural resistance of the tree before they have attained half their normal larval development. These galleries soon fill with brown scar tissue and are quite apparent in the cambium (figure 3). The attacks responsible for the development of these incipient galleries are considered as incipient attacks. The absence of incipient galleries and cambium injury of any kind on the check trees indicated freedom from borer attack. The fact that the borer larvae were able to complete their larval development on the cut tree while they could survive on the half-girdled tree only long enough to make incipient galleries, and were not able to enter the check tree far

A - A gallery on a section of tree No. 81, caged on June 25, 1936. The larva from this gallery was in its bark cell when the tree was peeled in October. In the lower right may be seen a larva which was just beginning to tunnel into the bark.

B - Practically mature larvae still feeding in the cambium when the tree was examined in October. This photograph also shows a section from the caged portion of tree No. 81.

Figure 2

A - Incipient galleries in a green tree in an old blow-down area. Although heavy attack had occurred during the 1938 season, no living larvae were present when the tree was examined in October. This tree was severely exposed, but apparently was not sufficiently weakened to allow successful attack. (10331)

B - A "close-up" of a portion of the above incipient galleries in cambium tissue. Note scar tissue filling the galleries. None of the larvae had tunneled deep enough to reach the wood. A 1-inch scale may be seen in the lower center. (10342)

Figure 3

enough even to scar the cambium, indicates the secondary nature of hemlock borer damage. This evidence would indicate that this insect is able to complete its life cycle only in weakened trees which, although still green, are actually slowly dying and probably will be dead within a few years even if not attacked by the borer.

Effect of Repeated Borer Attack on Vigorous Trees

Five vigorous middle-aged trees of Plot 46 were caged and infested in a similar manner to observe what effect, if any, would result from heavy, artificially introduced attack. Five check trees were also selected. This plot is located in one of the densest, most vigorous stands on the reservation. Twenty female and ten male beetles were field-collected and placed in each cage on June 24 for oviposition. It is planned to place ovipositing beetles in these cages each year to observe if repeated attacks will weaken the trees and render them susceptible to borer attack.

Incipient Attack Studies

Collections of blocks showing the galleries formed by incipient attacks were made from stands adjacent to certain sample plots (figure 4). A few of these galleries were found in wood laid on as early as 1902. Numerous gallery scars dating back to 1934 and 1935 were found in green trees of the 1933 and 1934 blowdown areas. Seventy-seven of these incipient attacks were counted on one 16-foot log in the Camp 24 area. Only a very small percentage of the larvae causing incipient attacks succeed in tunneling deep enough to etch the wood and leave a scar, and therefore the few gallery scars found represent only a very small portion of the

Figure 4

Callous tissue formation over an old incipient attack. Shows borer galleries etched in wood laid on in 1934. The tree on which this scar was found died during 1937-1938. Examined August 1938.

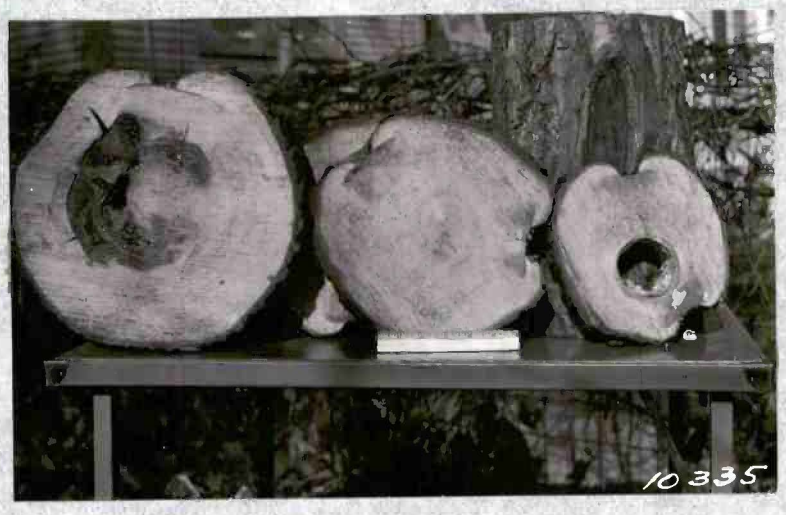
actual attack which took place.

This phenomenon of heavy, localized incipient borer attack immediately following blowdown illustrates the relationship between heavy borer attack and periods causing abnormal decadence in the forest, such as drought, or heavy windstorms which cause blowdowns. The fact that many trees survived heavy attack 4 years ago and were alive when examined is additional evidence that this insect is secondary rather than primary. The presence of galleries dating back to 1902 indicates that the hemlock borer has been present on the reservation for a long time, but was not able to develop to a large population until severe drought made conditions favorable.

Stem Analysis Studies

An examination was made of a number of blazed trees on section lines for which survey notes were available giving the dates on which the lines were established and re-surveyed. Chips were removed from some of the trees, and cross sections through the blazed area were taken from five trees (figure 5, A and B). A count of the annual rings showed that no rings had been dropped from the base of the trees during the drought period.

Cross sections were taken at 15-foot intervals from the five felled trees. There appeared to be a difference of two to four rings between the number of annual rings laid on at the base and those laid on at the top during the last 31 years. A striking combination of wide and narrow rings laid on during an 8-year period immediately prior to the last 31 years was used to standardize the cross sections. It is probable that the dropping of these rings occurred during the drought period. A more detailed study of this phenomenon is planned in 1939.



A - Cross sections from bases of five hemlock trees bearing section line survey blaze scars.

B - Cross section of section corner tree of Sections 32, 35, 5, and 4, T. 30, R. 15 of Menominee Indian Reservation, showing six annual rings since last re-survey blaze in spring of 1933 by U. S. General Land Office. Tree cut October 21, 1938.

Figure 5

CLIMATOLOGICAL DATA

Climatological phenomena, such as drought, high temperature, and high winds, were observed to have primary influence on the hemlock borer situation on the Menominee Reservation. Extreme heat has characterized the majority of the growing seasons of the 1931-37 period. High winds of near tornado velocities not infrequently followed severe heat waves, and heavy blowdown damage occurred in 1933, 1934, and 1936. As reported in last year's survey, 175,000,000 board feet of hemlock-hardwood timber have been blown down since 1932.

Study of Precipitation Records for Central Wisconsin

As weather records prior to 1936 are not available for any part of the reservation, the severity of the prolonged drought period of 1930-37 can best be illustrated by a study of the precipitation records of the three closest Wisconsin weather bureau stations. These stations are at Antigo, Shawano, and Wausau, located airline respectively about 20 miles northwest, 17 miles southeast, and 40 miles west of the Indian village of Neopit, which is the more centrally located of the two villages on the reservation.

The total summer deficiency in precipitation at these stations for the 1930-37 period was 26 to 28 inches (table 5). The most severe summer droughts occurred in 1931 and 1932, when deficiencies of about 30 percent were recorded. The lowest annual precipitation of this period occurred in 1932 and 1933 (table 6). A comparison of the 1938 precipitation at Neopit,[1] Antigo, Shawano, and Wausau is shown in table 7. It was reported locally that frequently during the 1930-37 period neighboring towns received light rains which missed the reservation. Even in the wet season of 1938, the total

[1] 1938 precipitation records at Neopit were furnished by Mr. Richard Delaney, Forest Supervisor, Menominee Indian Reservation.

Table 5

Summer Precipitation and Departure from Normal
April to August, 1930 to 1938 Inclusive

Year	Antigo		Shawano		Wausau	
	Precipitation (Inches)	Departure from Normal	Precipitation (Inches)	Departure from Normal	Precipitation (Inches)	Departure from Normal
1930	15.72	-1.86 [1]	13.60	-2.45 [1]	16.92	-1.21 [1]
1931	11.36	-6.22	10.91	-5.14	12.39	-5.74
1932	11.22	-6.36	12.28	-3.77	10.68	-7.55
1933	13.77	-3.81	13.99	-2.06	13.97	-4.16
1934	16.82	-0.76	14.05	-2.00	15.71	-2.42
1935	15.58	-2.00	14.48	-1.57	18.23	+0.10
1936	16.70	-0.48	12.31	-4.20	15.74	-1.93
1937	11.63	-5.55	11.42	-5.09	12.25	-5.42
Total Summer Deficiency 1930-37		-27.04		-26.28		-28.33
1938	22.85	+5.67 [1]	18.76	+2.25 [1]	29.63	+11.86 [1]

[1] The annual climatological reports for 1930 and 1938 were not available; therefore the departures from normal were calculated with reference to the normals of 1931 and 1937 respectively.

Table 6

Annual Precipitation
1930 - 1938

Year	Antigo		Shawano		Wausau	
	Precipitation (Inches)	Departure from Normal	Precipitation (Inches)	Departure from Normal	Precipitation (Inches)	Departure from Normal
1930	27.09	-2.45 [1]	24.12	-4.70 [1]	27.15	-4.98 [1]
1931	27.38	-2.17	30.42	+1.60	27.57	-4.54
1932	25.89	-3.66	25.22	-3.60	23.05	-9.10
1933	24.55	-5.00	26.55	-2.47	25.09	-7.02
1934	34.54	+4.99	31.38	+2.56	34.06	+1.95
1935	27.62	-1.93	26.97	-1.85	30.67	-1.44
1936	27.96	-1.49	28.16	-1.58	27.43	-3.47
1937	25.84	-3.61	29.14	-0.60	25.27	-5.63
1938	42.04	+12.09 [1]	40.06	+10.32 [1]	48.72	+17.82 [1]

[1] The annual climatological reports for 1930 and 1938 were not available; therefore the departures from normal were calculated with reference to the normals of 1931 and 1937 respectively.

Table 7

1938 Precipitation during Spring and Summer
(In Inches)

Month	Antigo	Shawano	Wausau	Neopit
April	4.13	1.99	4.43	2.89
May	5.99	5.35	6.26	6.26
June	4.25	2.94	6.76	2.30
July	3.62	3.27	4.20	3.48
August	4.86	5.21	7.88	4.55
Total	22.85	18.76	29.53	19.48

summer precipitation at Neopit was only .72 of an inch more than that of the lowest of the three stations. It therefore can be assumed that the precipitation at Neopit during the drought period approximated more nearly that of the lowest station rather than that of the highest.

SAMPLE PLOT STUDIES

Studies during 1938 included examining 57 permanent sample plots, 8 established in 1929 as growth study plots by the forestry department of the Menominee Indian Reservation, and 49 established in 1937 by the Bureau of Entomology and Plant Quarantine. In addition to these plots, the majority of which are in pure or nearly pure hemlock areas, ten 1/2-acre plots were established in 1938 to give information on the activity of the hemlock borer in thrifty mixed hardwood-hemlock stands and in young hemlock stands. Six of these new plots were located on the Menominee Reservation and 4 on or near the Nicolet National Forest.

The Reservation Growth Study Plots

When the Menominee growth study plots were established in 1929, height, diameter breast high, and general condition were recorded for each tree. These records were taken again in 1929 by the forestry department, and in 1938 the plots were examined by the writer in cooperation with this department. In addition to the above records, the degree of borer infestation and the species and diameter of all stumps on the plots were recorded in 1938. The tree mortality is shown in table 8.

Table 8

1929-38 Tree Growth Rate
Menominee Indian Reservation
Forestry Department Permanent Sample Plots

Plot No.	Total Trees Fall 1929	Hem-lock Fall 1929	Green Trees at Close of 9-yr. Period	6-yr. Period 1929-35 Inclusive: Total DBH Increment Inches	6-yr. Period 1929-35 Inclusive: Ave. Ann. Diam. Inc. Inches	6-yr. Period 1929-35 Inclusive: Trees Dying in Period	6-yr. Period 1929-35 Inclusive: Trees Wind-Broken	3-yr. Period 1935-38 Inclusive: Total DBH Increment Inches	3-yr. Period 1935-38 Inclusive: Ave. Ann. Diam. Inc. Inches	3-yr. Period 1935-38 Inclusive: Trees Dying in Period	3-yr. Period 1935-38 Inclusive: Trees Wind-Broken	1929-38 Tree Mortality by Species (Percentage): Hemlock	1929-38 Tree Mortality by Species (Percentage): Hardwood
1	32	2	Hemlock 1:	1.7	.028	1	0	.5	.017	0	0	0	
			Hardwood 1/ 24:	13.0	.093	2	0	9.2	.127	1	0		10
2	40	5	Hemlock 5:	1.4	.047	0	0	1.0	.066	0	0	0	
			Hardwood 33:	17.9	.090	1	0	6.8	.068	1	0		6
3	45	38	Hemlock 31:	12.2	.066	7	0	8.4	.090	0	0	19	
			Hardwood 7:	3.0	.083	2	0	2.6	.144	0	0		0
4	36	31	Hemlock 27:	17.6	.109	2	0	10.8	.133	2	0	13	
			Hardwood 3/ 5:	1.9	.063	0	0	1.5	.100	0	0		0
5	21	2	Hemlock 2:	0.9	.075	0	0	0.5	.083	0	0	0	
			Hardwood 17:	15.8	.135	1	0	7.6	.149	0	1		9
6	69	66	Hemlock 2/ 33:	9.9	.050	17	0	5.6	.056	14	0	47	
			Hardwood 3/ 3:	1.2	.068	0	0	0.5	.055	0	0		0
7	38	34	Hemlock 17:	5.8	.057	5	0	4.2	.041	11	1	50	
			Hardwood 3/ 2:	.2	.016	0	0	.1	.017	0	0		0
8	39	23	Hemlock 21:	5.7	.045	0	1	3.1	.049	1	0	9	
			Hardwood 16:	4.8	.050	0	0	4.7	.098	0	0		0

1/ Three hardwoods measured for first time in 1935 not included.

2/ Two green trees omitted from growth calculation due to contradictory diameter measurement records. These are included in the mortality calculation.

3/ All birch trees, majority of which were suppressed trees.

It was found that the total mortality of hemlock during the 9-year period 1929-38 in the plots where this species predominated (Nos. 3, 4, 6, 7, 8) was 61, or 32 percent. Only 2 of the 33 hardwood trees of these 5 plots were killed during this 9-year period, 1 by knockdown and 1 by blowdown. Death of only 2 of the 61 dead hemlocks could be attributed directly to blowdown.

Drought and heat appear to be the principal factors causing the hemlock mortality. These are supplemented by the rather even and overmature age condition of the stands and the fact that much of the hemlock is found on a medium site. Such a site is too low in fertility to support a hardwood stand, but hemlock can successfully maintain itself as long as other environmental factors are favorable. It becomes a poor site even for hemlock as soon as one of the principal environmental factors, such as precipitation, ceases to be favorable for any lengthy period.

The differences in tree mortality of Plots 6, 7, and 8 substantiate the above statements, and probable reasons are discussed in detail as they have a bearing on the causes of mortality in the area as a whole. Plot 6 is located on a small levee-like knoll which is well drained on all sides. There is a cedar swamp to the north and east. The stand was rather heavily cut over during the logging operation just prior to 1929, about 50 percent of the volume being removed. A tally of the stumps in 1938 showed a total of 41 within the borders of the plots. Of this number, 23 hemlock of 10" DBH or over, having an estimated volume of 3,400 board feet, had been cut in the previously mentioned operation. Three white

pines with an estimated scale of about 1,360 board feet had been logged about 40 years earlier.

Sixty-nine trees with a total volume of 4,450 board feet remained after logging, and all were living when the sample plot was established in 1929.

During the period 1929-38, 31 of the 66 hemlocks on this plot (No. 6) died (17 prior to the fall of 1935 and 14 more prior to the fall of 1938). These trees represented a merchantable volume (trees over 9" DBH) of about 1,350 board feet, or about one-third of the residual volume left by the logging operation (table 9).

Plot 7 is located in a practically pure hemlock stand. The plot is on the top of a low, flat ridge and is well-drained. The area was selectively logged in 1930, and 10 trees on the plot were cut. These trees represented a volume of about 1,200 board feet, or about a 20 percent cut.

During the 1929-38 period, 16 of the 30 hemlock trees of this plot died, 5 prior to the fall of 1935, and the remainder between then and the fall of 1938. In addition 1 tree was broken by wind action. Six of these trees were in the 20" to 28" DBH group and 4 in the 16" to 18" group (table 10) Because the majority of the dying trees were from the large diameter classes, these trees totaled 3,890 board feet, or about two-thirds of the volume of the stand.

Plot 8 is just outside the area cut selectively in 1930. The plot contains a mixed stand of hemlock and hardwoods. The adjacent area to the west of the plot contains a large percentage of hardwoods and that on the east contains a large percentage of hemlock. The

Table 9

Gross Volume Table - in Board Feet
Menominee Indian Reservation
Forestry Department Permanent Sample Plots

Plot No.	Green Timber: Maple	Other Hard-woods	Hem-lock	Total	Dead Timber: Hard-woods	Hem-lock	Total	1938 Volume: Green & Dead	Volume Removed Based on Stump Diameter: Hard-woods	Hem-lock	Total	Approximate Volume in Recent Past * (Prior to 1929): Per Plot	Per Acre
1	1,636	290	70	1,996	0	360	360	2,356	1,580	0	1,580	3,936	15,700
2	611	2,420	0	3,031	20	0	20	3,051	950	120	1,070	4,121	16,500
5	1,253	1,040	0	2,293	250	0	250	2,543	3,040	140	3,180	5,723	22,900
6	All Hardwoods	400	2,700	3,100	0	1,350	1,350	4,450	1,860 1/	3,400	5,260	9,710	38,840
7		160	1,670	1,830	0	3,890	3,890	5,720	600	600	1,200 2/	6,920	27,680
8		5,070	3,410	8,480	0	270	270	8,750	0	0	0	8,750	35,000

1/ Total volume for three white pine trees. No hardwood of merchantable size cut on this plot. These pines had been cut long before 1929 (probably 40 years previous). Therefore they are not included in calculation of "volume in recent past".

2/ Estimated volume. Complete stump diameter records not available for this plot. Ten trees, seven of merchantable size, had been cut. Aggregate volume for six of these trees was 940 board feet. Estimated volume for other four trees conservatively placed at 260 board feet.

* Data on the volume increment due to growth during this period of 20 years or more is not available. This calculated volume therefore exceeds the actual volume present by the amount of the volume increment.

Table 10

1938 Tally for Plots 6, 7, and 8
Menominee Indian Reservation
Forestry Department Plots

DBH Class	Plot 6				Plot 7				Plot 8			
	Green Trees		Dead Trees		Green Trees		Dead Trees		Green Trees		Dead Trees	
	Hard-wood	Hem-lock	Hard-wood	Hem-lock	Hard-wood	Hem-lock	Hard-wood	Hem-lock	Hard-wood	Hem-lock	Hard-wood	Hem-lock
Under 9"		3		10		7		2 1/	2	8		
10"		9		9		3		3 1/	1	2		2/
12"	1	10		9	1	2		1	2	2		1 2/
14"	1	12		3	1	2		1		1		
16"		1						2	1	2		1
18"	1					1		2	2	1		
20"								4	3	2		
22"						2		1	2	2		
24"									1	1		
26"									1			
28"								1	1			
30"												
Total No. of Trees	3	35		31	2	17		17	16	21		2
Gross Vol. for trees of 10" and over	400	2700		1350	160	1670		3890	5070	3410		270

1/ One windbroken

2/ Windbroken

plot is located about one-half mile west of Plot 7, on the top of the same ridge. The site conditions for this plot are better than for the other two, although the site differences between Plots 8 and 7 are much less than those between Plots 8 and 6. This stand has not been logged.

During the period 1929-38, only two hemlock trees in this plot died. One, a 12-inch (DBH) tree, died prior to the fall of 1935 when its top was broken off at 35 feet, probably by wind. The second tree died apparently from natural causes. This tree was of intermediate crown class, 15" DBH, had been dead for about two years, and had the shoestring rot (Armellaria mellea) on all the main roots and evidence of very light hemlock borer attack. The latter was entirely too light to have had any part in causing its death. A "ring count" showed a 17-inch (DBH) codominant hemlock to be 240 years old. The majority of the larger trees of both this plot and Plot 7 are from 250 to 275 years old.

A comparison of these three plots brings out the strikingly low tree mortality of Plot 8, which was only 9 percent as compared to 47 percent and 50 percent mortality for Plots 6 and 7 respectively. It is the opinion of the writer that drought and heat, causing high soil temperatures, are responsible for the high tree mortality of Plots 6 and 7. The logging operations preceding the hot dry seasons intensified the injury in proportion to the amount of opening and exposure caused by the operation. In the case of Plot 7 the overmaturity of many of the dominant trees made them less resistant to the drought. This stand had also been opened to a limited extent by logging, although to a lesser degree than had Plot 6. As the

trees became more weakened and the death of trees opened the canopy during the last 3 years, the mortality rate increased fourfold.

In the case of Plot 8, table 10 shows that 16 hardwood trees compose 58 percent of the volume. Two-thirds of these hardwoods were between 16" and 28" DBH, and their crowns formed quite a protective canopy over the area. Although many of the hemlocks in this plot were as old as those of Plot 7, the protection from exposure and heat afforded them by the hardwoods more than offset any limited effect which age might have exerted. This example illustrates the primary nature of drought and heat as compared to overmaturity and other subordinate factors which have had a minor part in bringing about the present decadent stand condition.

The generally greater diameter growth and lower tree mortality for the hardwood plots indicate that the hardwood stands as a whole suffered less severe injury from the drought than did the hemlock. This is probably due in part to the fact that the hardwoods in general have a deeper root system and demand better site conditions.

The Hemlock Borer Sample Plots

The 49 permanent sample plots established on the Menominee Reservation in 1937 and 6 additional plots established in the summer of 1938 were examined in October. Records of borer infestation, mortality of hemlock trees, amount of reproduction, and number of stumps were taken in each plot. The data on the last item are to be used in determining the former stand density and composition, and will be included in the final report.

Increment cores for the determination of diameter growth for

the current and preceding seasons were taken from representative trees in each plot. A slight increase was shown for the current year as a result of the heavy precipitation during the 1938 growing season, but the response resulting from this increased precipitation should be more apparent in 1939.

General observations had shown that the annual tree mortality in areas severely injured by blowdowns was considerably higher than that in areas not injured by windthrow. This was true even in cases where no additional blowdown had occurred within the past five years. The plots are therefore grouped according to their recent history. The average tree mortality and volume of dead timber involved has been calculated for the hemlock types that suffered blowdown injury and those that did not (tables 11 and 12).

The gross volume for hemlock stands in Wisconsin is about 15,000 board feet per acre. This figure agrees approximately with those obtained by Delaney in a survey made on the Menominee Indian Reservation in November 1938. He found the present gross volume of green timber for the hemlock type to be, in board feet per acre, about 11,000 for the logged areas and 18,000 for the uncut areas. The mortality was determined for the period between the fall of 1937 and the fall of 1938. For the 32 plots which never suffered noticeable blowdown damage, the average mortality, by volume, was 2,323 board feet per acre, or approximately 15.4 percent of the volume of the average hemlock stand. The bulk of the dead trees were hemlock, with a volume of 2,033 board feet. Yellow birch was the most numerous hardwood species, with 101 board feet per acre (table 11).

Table 11

Tree Mortality and Gross Volume of Dead Timber Involved (Based on Thirty-two 1/2-acre Sample Plots in Stands Not Injured by Blowdowns)

MORTALITY FIGURES

Species:	Hemlock							Yellow Birch						Other Species					
DBH Class	2-8	9-14	15-20	21-26	27-32	33-38	Total	2-8	9-14	15-20	21-26	27-32	Total	2-8	9-14	15-20	21-26	27-32	Total
Total Trees Dead 1937	32	43	59	24	19	2	179	0	4	3	1	1	9	4	0	1	2	0	7
Additional Trees Dead 1938	32	32	36	20	8	0	128	3	2	0	3	0	8	9	2	3	2	1	17

VOLUME TABLE
Average Volume per Acre in Board Feet

Species:	Hemlock							Yellow Birch						Other Species						Grand Total	Per-cent
DBH Class	9-14	15-20	21-26	27-32	33-38	Total		9-14	15-20	21-26	27-32	Total		9-14	15-20	21-26	27-32	Total			
Volume Trees Dead 1937	188	996	870	1,330	218	3,602		12	40	32	57	141		0	15	75	0	90			
Volume Additional Trees Dead 1938	140	608	725	560	0	2,033		6	0	95	0	101		9	45	75	60	189		2,323	15.4

Note: The thirty-two plots were Nos. 2,3,7 to 10, 15 to 18, 23,25 to 34, and 36 to 46.
The mortality of 2,323 board feet amounts of 15.4 percent of the volume of a normal stand (15,000).

Table 12

Tree Mortality and Gross Volume
of Dead Timber Involved
(Based on Twelve 1/2-acre Sample Plots in Stands Injured by Blowdowns)

MORTALITY FIGURES

Species	Hemlock							Yellow Birch					Other Species			
DBH Class	2-8	9-14	15-20	21-26	27-32	33-38	Total	2-8	9-14	15-20	21-26	Total	2-8	9-14	15-20	Total
Total Trees																
Dead 1937	10	21	14	3	2	1	51	2	0	2	2	6	1	1	0	2
Additional Trees Dead 1938	22	30	25	13	3	0	93	1	2	1	2	6	4	0	1	5
Green Trees Cut in 1937-1938 Logging	20	1	6	2	0	0	29	1	0	0	0	1	2	4	1	7

VOLUME TABLE
Average Volume per Acre in Board Feet

Species	Hemlock						Yellow Birch				Other Species			Grand Total	Per-cent
DBH Class	9-14	15-20	21-26	27-32	33-38	Total	9-14	15-20	21-26	Total	9-14	15-20	Total		
Volume Trees Dead 1937	245	630	290	373	290	1,828	0	72	169	241	10	0	10		
Volume Additional Trees Dead 1938	350	1,125	1,257	560	0	3,291	16	36	169	221	0	40	40	3,552	23.7
Green Volume Cut in 1937-1938 Logging	12	270	193	0	0	475	0	0	0	0	40	40	80		

Note: The twelve plots were Nos. 1, 4 to 6, 11 to 14, 22, and 47 to 49.

The blowdown-injured areas had an average mortality, by volume, in 1938 of 3,552 board feet per acre, or approximately 23.7 percent of the volume of a stand of normal stocking. However, since many of these stands were understocked, this frequently was actually 40 to 50 percent of the volume of the stand.

The greater amount of mortality in the blowdown area is probably due to two factors. First is the greater exposure of the tree trunks and surface soil to heat following the opening of the stands by blowdown. Next are root breakage and injury to a large portion of the residual stand not knocked down by the windstorm, which weakened the stand and made it more susceptible to attack by the shoestring rot and the hemlock borer.

SUMMARY

1. There is evidence indicating that the life cycle is generally 1 year, with possibly a 2-year cycle under less favorable conditions.

2. Pupation began about the first of June in 1938. For June pupation the pupal period appears to be from 2 to 3 weeks.

3. Beetle emergence commenced June 15 and continued into August. The peak was reached during the last week in June.

4. Parasite emergence commenced the latter part of June and continued into August. The peak was reached during the first half of July.

5. The maximum length of life for the beetles under caged conditions was 10 days.

6. The adult beetles were observed feeding on both a bark inhabiting moss (Dicranum montanum Hedw.) and the new foliage of the hemlock.

7. The eggs are usually laid singly in crevices or beneath flakes of bark.

8. Preliminary studies on the apparent phototrophic and temperature responses of the ovipositing beetles were made. Eighty percent of the oviposition observed were at bark surface temperatures between 82° and 92° F. Further study will be made next season.

9. Collecting of data on the biotic potential of the insect was begun this season and will be continued through next season.

10. The sex ratio was determined to be approximately 1 to 1.

11. The accumulation of data on egg incubation and mortality will be continued.

12. Observations on winter larval mortality are being made at bimonthly intervals.

13. The effectiveness of parasites and predators as a control factor has not been definitely determined, therefore the collecting of quantitative data was begun and will be continued through the 1939 season.

14. A 2-year study of the susceptibility of various tree conditions was begun in 1938. From first season observations it appears that the hemlock borer can successfully attack, and can mature in, only those trees that are very weak or dying.

15. Incipient gallery scars were found in wood laid on as early as 1902. This indicated that although the borers have been present in the stands on the Menominee Reservation for many years, they were not able to develop an outbreak population until conditions were made suitable by the heat and drought of the 1930-37 period.

16. The precipitation records of the weather bureau stations in the vicinity of the reservation show a total summer (April through August) deficiency for the 1930-37 period of 26 to 28 inches. The most severe summer droughts were in 1931 and 1932, when deficiencies of about 50 percent were recorded.

17. Drought and heat appear to be the principal factors causing the hemlock mortality . These are supplemented in many instances by the overmaturity of the stand and poor site conditions.

18. The average gross volume for hemlock stands in Wisconsin is about 15,000 board feet per acre. The average mortality in 1938 for the hemlock type which had not suffered noticeable blowdown damage was found to be 2,323 board feet (gross volume) per acre, or approximately 15 percent of the volume of an average hemlock stand.

19. The blowdown-injured areas had an average annual mortality volume of 3,552 board feet per acre, or approximately 23.7 percent of the gross volume of a stand of normal stocking. However, since many of these stands were understocked, this mortality was actually, in many cases, 40 to 50 percent of the volume of the stands.